Measuring the Economic Return to an Infrastructure Investment Using Interregional Price Gaps: a Natural Experiment *

Zhigang Li

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Abstract

The objective of this study is to measure the economic benefits of infrastructure investments. Specifically, I consider an investment in China that doubled the tracks of a one-thousand-mile-long railroad in 1994. This capacity expansion, intuitively, may gain welfare by increasing interregional trade and decreasing prices of traded goods. I first estimate the impact of this investment on price differences across regions. The identification relies on a key feature of my setting that the expansion in rail capacity only affects the trade of goods in one direction. I find that the investment significantly reduces interregional price gaps, and this effect is robust to both reduced-form and structural estimation techniques. In the second stage of analysis, using a partial equilibrium framework, I derive a welfare measure that transforms the estimated price-gap effect into welfare estimates. I find that the internal rate of return of the investment may significantly exceed the costs of capital in China.

Key Words: Infrastructure Investment, Interregional Trade, Chinese Economy
JEL Classification: H54, O18, R41

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Contact: School of Economics and Finance, The University of Hong Kong, Pokfulam, Hong Kong, P. R. China zli@econ.hku.hk.

1 Introduction

Infrastructure investments are hugely important economic activities.[1] About 4.5 percent of GDP was spent on public infrastructure in the U.S. throughout the 1990s.[2] This ratio recently reached 13 percent in China.[3] A long-standing question in the literature of infrastructure regards its production value: how much is additional infrastructure worth as production inputs? knowing this is obviously key to making infrastructure investments at optimal levels. Answering the question, however, is difficult since markets are generally missing for the service of infrastructure. Employing changes in transport costs, Fogel [7] found that the railroad industry only had a modest impact on American economic growth during the late nineteenth century.[4] In contrast, Aschauer [3], by estimating a production function with aggregated measures of infrastructure as inputs, suggested huge economic returns to infrastructure investments in the U.S. (1949-1985). Follow-up studies, mainly utilizing the aggregated approach, provided mixed results.[5] Gramlich [10] reviews this literature and points out a series of intrinsic identification problems, suggesting that the aggregate approach provides unconvincing estimates.

This study takes a disaggregated approach. In particular, I consider a specific investment that doubled the tracks of a thousand-mile-long railroad in China. A two-step procedure is introduced to infer the economic return to this investment. In the first step, the impact of

[1]Typical nonmilitary infrastructures include streets and highways, airports, electrical and gas facilities, mass transit, water systems, and sewers.

[2]Source: European Commission and OECD.

[3]Source: Patricia Darrow. China Country Commercial Guide FY2001. US&FCS Market Research Reports.

[4]This is often called the "social-savings" approach, referring to the savings in transport costs due to new transport infrastructure investments. Returns estimated by this approach were around 10 percent for railroad construction in the late 19th century. Mercer [15] refined the estimates as around 24 percent for the Central Pacific system after considering changes in railroad earnings, the savings to the shippers, the savings to the passengers, and incremental values of land. See O'Brien [19] and McClelland [14] for surveys and criticism of the literature.

[5]Following the Aschauer [3] approach, Holtz-Eakin [11], Munnell [17], and Rubin [21] also find results similar to his. Hulten and Schwab [12] and Tatom [23] point out the common-trends problem in data and consider regressions with first differences, finding insignificant effects of public capital. Munnell [18] and Tatom [24], in contrast, consider the co-integration approach and also find no impact of infrastructure capital. Morrison and Schwartz [16] choose to estimate cost but not to estimate production functions, finding reasonable returns to infrastructure investments with state-level data. Fernald [6] estimates the differential impacts of road stock on industries with varying dependencies on vehicles, and finds huge returns between 1950 and 1970, but small returns after 1970.

the investment on product-level price differences across regions is estimated. The amount of data required for this step can be significantly reduced by a structural price-gap model, which I construct within a simple trade framework. In the second step, this estimated price-gap effect is transformed into a measure of social surplus gains using a formula I derive from a partial equilibrium model. Intuitively, the investment in railroad may gain welfare by lowering interregional trade barriers, which can be approximated by the interregional price gaps.

Compared with the traditional literature, this study is able to better identify the causal effect of infrastructure investments on economy by taking advantage of two features of the empirical setting. First, pre-expansion capacity of the railroad was redundant in only one direction. Therefore, goods shipped in this direction should not have been affected by the expansion. Furthermore, their interregional price gaps can be used as a control group for the price gaps of goods shipped in the other direction. This natural experiment thus allows me to control for unobserved changes, e.g. common demand shocks, that may coincide with the investment and confound the estimated impact of expansion.

Second, the infrastructure investment in my setting is potentially exogenous to local economic conditions for two reasons. First, China underwent a structural change that significantly increased infrastructure investments nationwide after 1990. The investment in my setting may just be a consequence of this change. Second, the region I consider is separated from the rest of China by hundreds of miles of desert on one side, and is bordered by several Central Asian countries on the other. Therefore, the capacity expansion may have been used to strengthen the link between this region and the rest of China. Both reasons suggest that the investment may not have been caused by local economic conditions. It is important to note that, even if the railroad-expanding investment was made because local economy was expected to grow faster (thus making the investment endogenous), this would likely have biased my estimates against finding the effect of investment on interregional price gaps: the high local economy growth would have driven up the price gaps, while the capacity expansion would have lowered the price gaps.

Estimating the structural price-gap model, I find that price gaps of goods shipped in the capacity-binding direction shrank by 30 percent after the expansion. In contrast, the price gaps of goods shipped in the non-capacity-binding direction changed little after the expansion. This finding is further confirmed using a reduced-form approach. Plugging these estimates into the welfare measure, I find that the annual internal rate of return to the project is 15 percent in my most conservative case; whereas in my less conservative but still reasonable scenarios, the internal rate of return is found to exceed 50 percent per year. This range obviously exceeds the capital costs in China.

This study is related to three previously unrelated literatures. One is the economic integration literature, in which interregional price gaps are often used to measure the degrees of economic integration, e.g. Berkowitz and DeJong [4], O'Connell and Wei [20], and Shiue [22]. What factors may affect the price gaps, however, is rarely explored in the literature. Another is the empirical trade literature that estimates the effects of trade quotas, which are similar to the transport capacity restrictions in my case. The third vein of literature, mentioned earlier, measures the returns to infrastructure investments. This literature has not provided much evidence concerning investments on transport capacity, perhaps due to the difficulties in isolating the impact of capacity changes from the influence of other confounding factors — e.g. changes in other attributes of the transport facility such as length, changes in competing transport facilities such as highways, and changes in other trade impediments such as trade regulations. Moreover, the available studies on highway congestion mainly consider direct benefits accrued to road users in the form of cost, time, and accident savings, but not by gains to interregional trade, which is the focus of this study.

The following section details the empirical setting and graphically presents the relationship between the railroad capacity expansion and relative price gaps. It is followed by a section detailing the methodology I used to estimate the impact of the investment on price gaps and to infer gains in welfare. Section four considers empirical estimates of the price-gap effect. In section five I utilize estimates I obtained earlier to provide a lower bound to the social surplus gain and to compute the corresponding rates of return. The concluding section discusses possible directions for future research.

2 The Setting: Rail Expansion and Price Gaps

As I have mentioned, my identification of the effect of the infrastructure investment hinges on a natural experiment. Imagine the following setting: trade between city A and B can occur only through a transport structure connecting them; city A ships steel to city B, and city B ships VCRs to city A. Since steel is cheap and heavy while VCRs are expensive yet light, the capacity of the transport structure is saturated for shipping from city A to B but not in the other direction. One day, the capacity of the transport structure is expanded. This expansion, obviously, should only affect the trade from A to B since only the shipping in this direction is restricted by capacity. The shipping from B to A thus serves as a control group. My real setting is shown below.

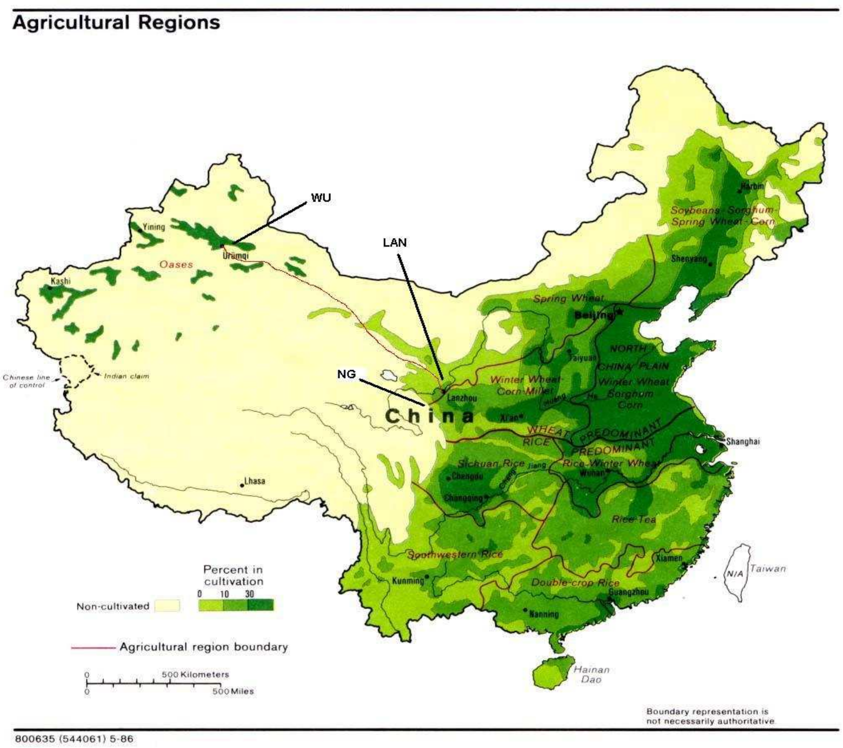

Figure 1: A Map of China (Agricultural Regions)

Following is a map of China. City A in my setting is WU (in the northwestern corner of

China), and city B is LAN (near the center of China).[6] Separated by a largely uncultivated area, LAN and WU are connected by a 1200-mile-long railroad (the thin line between them). The majority of shipment between WU and the rest of China occurs through the LAN-WU railroad. In 1995, rail-shipping accounts for around 95 percent of the trade (in tons) between WU and the rest of China (by *Chinese Transportation Yearbook* [2]).[7] Therefore, LAN serves as a port for the rest of China in its trade with WU.

2.1 Capacity Expansion and Asymmetric Trade Volumes

The LAN-WU railway was built in the 1960s, and there has been no major change to the railroad until the mid-1990s. A "capacity-doubling" project, which started on September 16, 1992 and ended in October 21, 1994, doubled the tracks for about 80 percent of the railroad[8] and expanded its maximum capacity from 12 to 25 million tons per year (in each direction).

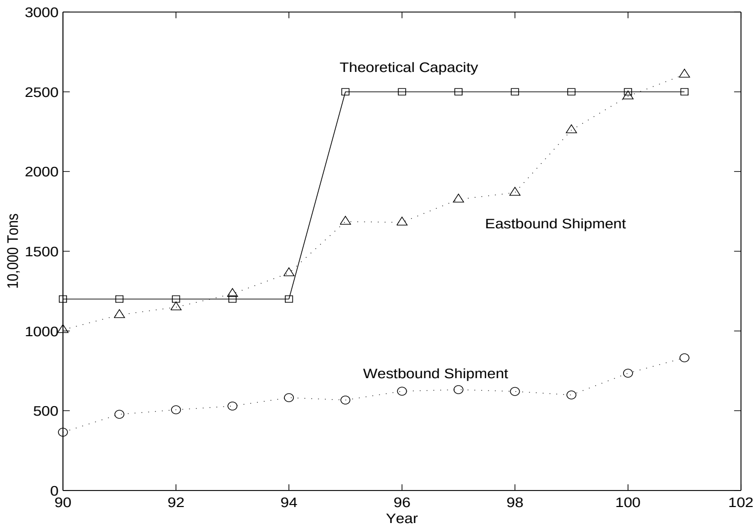

Figure 2: Capacity and Actual Flows of the LAN-WU Railroad, Measured in Tons
Source: *Chinese Transportation Yearbook*

Figure 2 depicts the maximum capacity (solid line) and the annual shipment volumes

[6]Capital of the Xinjiang province, WU is officially named Urumqi. LAN is the capital of the Gansu province and its official name is Lanzhou. The populations of both cities exceed one million.

[7]This is due to the geographical obstacles and the poor quality of inter-province highways.

[8]This portion with capacity upgrading lies between WU and a city called Weiwu; the length of this portion is about 1,000 miles.

(dotted lines) on the LAN-WU railroad. Data on actual volumes are given for the westbound (LAN-to-WU) shipments and eastbound (WU-to-LAN) shipments. *Significantly different patterns emerge for eastbound and westbound shipping.* The eastbound volumes show that as the the maximum capacity increased, so did eastbound shipping. Before 1995, eastbound shipping volumes increased by around 1 million tons per year; in 1995, the eastbound volumes jumped by 3.23 million tons. In sharp contrast, westbound shipping volumes were less than half of the maximum capacity, and they were not affected by the rail-upgrading. These patterns suggest that the demand for LAN-WU eastbound shipping was so large that the rail capacity was binding. In contrast, the demand for westbound shipping was small enough that it was not restricted by the railroad capacity. This pattern is reasonable considering that the Xinjiang province (of which WU is the capital) and the countries to its west mostly produce heavy industrial intermediate goods and import light-weight final consumer goods.[9]

2.2 Interregional Price Gaps

Having shown the impact of the capacity expansion on trade flows, I present graphical evidence below for the effect of the expansion on price differences across LAN and WU. Essentially, I compare time series patterns of the price gaps of goods shipped eastbound (from WU to LAN) to those shipped westbound (from LAN to WU), and examine if they can be explained by the capacity expansion. I also compare the LAN-WU price gaps with the price gaps between LAN and NG, a city located about 120 miles to the west of LAN[10], to ensure that economy-wide product-specific shocks, e.g. changes in price regulations, do not confound the effect of the capacity expansion. The LAN-NG price gaps can serve as a control group because the transport infrastructure connecting LAN and NG has changed little in the 1990s (by *Chinese Transportation Yearbook* [2]).

[9]Since petroleum products were among the goods shipped eastbound, one possible concern is that the westbound shipping capacity was partially taken up by the empty returning tanks used to shipped the petroleum products. If this were true, the westbound shipping might also be restricted in capacity although it did not seem to be. I would argue that this is not the case because if it were, the westbound shipping volumes should also jumped up in 1994 due to the expanded capacity, unless all new capacity was used to shipped petroleum products. This did not seem to happen.

[10]The official name of NG is Xining, which is the capital and economic center of the Qinghai province.

Market prices of over fifty specific goods have been surveyed on the same day of each month in 29 capital cities of China ever since 1992 (see *Chinese Prices* [1]). The resulting price data set is highly disaggregated and avoids losing information due to data-smoothing over time. Among the products surveyed, thirty-five (12 industrial goods and 23 agricultural products) have observations spanning the pre- and post-capacity-expansion periods.[11] Using their prices, I calculate corresponding price gaps as follows:

$$LAN \cdot WU\ Price\ Gap \quad = \quad LAN\ Price \ - \ WU\ Price \tag{1}$$

$$LAN \cdot NG\ Price\ Gap \quad = \quad LAN\ Price \ - \ NG\ Price \tag{2}$$

Figure 3 plots the price-gap time series for four products (gasoline, diesel, hot-rolled and cold-rolled thin sheet steel) that I find to be shipped from WU to LAN (eastbound).[12] The price gaps of all these four products experienced sharp drops around mid-1994. This reduction in price gaps coincides with the completion of the LAN-WU upgrading project (shown by the vertical dotted line), suggesting a relationship between the drop of price gaps and the change of capacity.[13]

This shrinkage of price gaps, however, may have alternative explanations. For example, construction of the second track might interrupt rail operation, thus driving up the price gaps in 1993 and 1994 (an upward trend of price gaps is obvious in figure 3 for all the four

[11] These products are 70# gasoline, 0# diesel, 10-20mm round steel (normal carbon level), 19-24mm thread steel, 6.5mm hot-rolled steel rod, 1mm cold-rolled sheet steel, 1mm hot-rolled sheet steel, 20mm hot-rolled sheet steel, 2-6# angle steel, Sodium Hydroxide (98%), Sodium Carbonate (98.5%), cement (normal), flour (normal), rice (grade 2), corn flour (grade 2), soybean (grade 1), vegetable oil (grade 2), Chinese cabbage (grade 1), cabbage (grade 1), Chinese chives (grade 1), cucumber (grade 1), tomato (grade 1), eggplant (grade 1), radish (grade 1), green pepper (grade 1), potato (grade 1), watermelon (grade 1), fresh pork (boneless), beef (boneless), mutton (boneless), chicken (medium), egg (fresh), belt fish (medium), silver carp (medium), and tofu.

[12] Information on the products' trade directions is not directly available. In order to determine whether a product is shipped from WU to LAN, I infer the product's trade volume by subtracting the product's local consumption from its local production in WU. I find this trade volume to be positive and large only for these four products, suggesting that they are shipped from WU to LAN (see appendix for detail).

[13] The price gaps of gasoline and diesel actually shrank a little bit earlier than the completion of project. This could be because inventory holders released part of their inventory before the expected drop in prices due to the capacity expansion. This would suggest that my estimate of the price gap change is a lower bound to the actual change.

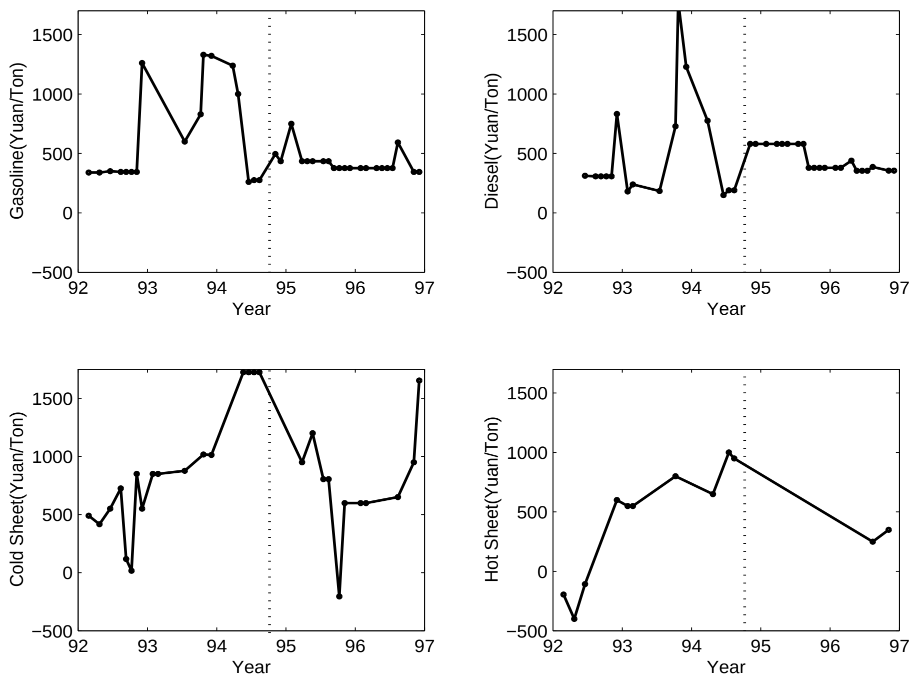

Figure 3: The Treatment Group

products)[14]; therefore, the drop in price gaps might simply reflect the restoration of the rail operation to normal order. Another reason could be that changing the LAN-WU railway from single to double track may increase the operation efficiency, thereby reducing shipping costs and the LAN-WU price gaps. Last but not least, weakened interregional trade barriers between

[14]This construction theory is not supported by the trade data since, as shown by figure 2, the eastbound shipping volumes actually increased for 1993 and 1994. Some other stories may also explain this upward trend in price gaps before 1995. First, it may be caused by a reallocation of capital to Xinjiang preceding the capacity expansion. For example, knowing that the rail capacity would double, investors might have increased their investment in the Xinjiang oil drillers, processors, or steel mills. If significant investments happened around the end of 1992, the price gaps of the four products would widen as the marginal costs of producing these goods decreased in Xinjiang. This theory is not supported by data either. According to table 8, no significant increases of output levels were observed for any of the four products in 1993. Yet another possible cause to the price-gap decrease is the change of national price regulation policy around the end of 1992. According to the *Chinese Price Yearbook*, official caps on oil and steel products prices were lifted on September 1, 1992. Therefore, the upsurge of price gaps around the end of 1992 may simply reflect a transition of the price system to a market equilibrium. The fourth possible cause is the completion of a railroad between WU and Kazakhstan in 1992. This could increase the demand for LAN-WU eastbound shipping (see appendix for more detail) and make the capacity restrictions more stringent, thus driving up the price gaps. This explanation does not seem to be very likely given that the westbound shipping volumes, which should also be affected by the increased Xinjiang-Kazakhstan trade, changed very little according to figure 2. No matter which of these latter three stories are true, they can not explain why the price gaps would drop so dramatically following a period of rise.

LAN and WU due to other factors, e.g. government regulation, could also decrease LAN-WU price gaps. In order to examine if these alternative factors have generated the shrinkage of eastbound LAN-WU price gaps, below I present the patterns of westbound LAN-WU price gaps and of price gaps between LAN and NG.

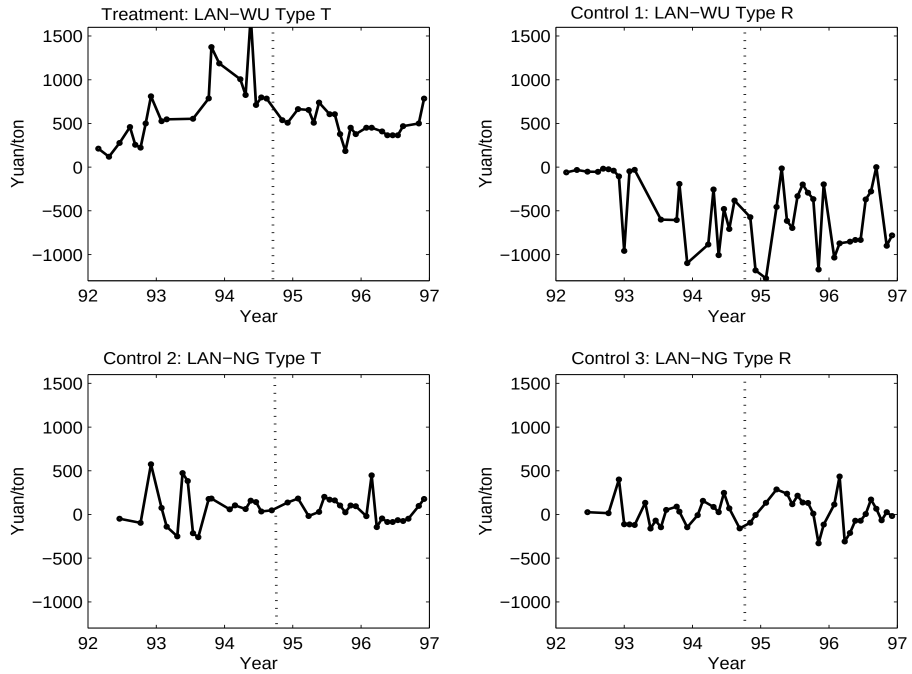

Figure 4: Treatment vs. Controls

For convenience, I call the four products shipped from WU to LAN type T products, whose LAN-WU price gaps constitute the *treatment* group. The remaining 31 products will be referred to as type R products, whose *westbound* LAN-WU price gaps (goods that are cheaper in LAN than in WU) constitute my first *reference* group. Westbound LAN-WU price gaps imply that the prices were cheaper in LAN than in WU, so the goods tended to be traded westbound from LAN to WU. If they were not traded, their price gaps obviously would not be affected by the capacity expansion; if they were traded, their price gaps still should not be affected directly by the expansion since the shipping from LAN to WU was not restricted by the railroad capacity.

The top-left panel of figure 4 plots the time series of the treatment group. It shows a sharp drop of price gaps around the end of 1994, which is consistent with my observation from figure 3. The top-right panel plots my first reference group, which shows a pattern strikingly different: the price gaps appear unaffected by the expansion. This suggests that the alternative factors (construction interruption, shiping-cost reduction, and government regulation) were not important since, if they were, the westbound LAN-WU price gaps should also be affected.

Next, I turn to the average LAN-NG price gaps, which are plotted in the two bottom panels of figure 3 for both type T and type R products. The price gaps of type R products are quite stable, showing slight upward trends over time. In contrast, the price gaps of type T products show a sign of shrinkage in 1993. This, however, happened much earlier than the expansion. In sum, the graphical patterns of LAN-NG price gaps does not support for the theory that a common shock to interregional trade barriers within China (e.g. changes in government price regulation) lowered price gaps of goods shipped from WU to LAN.

2.3 The Endogeneity Issue

A key question relevant to my empirical identification is the cause of the investment. The concern is that the investment in the railroad was made because the regions I consider were anticipated to grow faster. This endogeneity would introduce a correlation between the railroad expansion and changes of the price gaps, thus confounding the causal effect of the investment on the price gaps.

This endogeneity issue, however, does not seem to be a serious problem in my case. First, the investment was potentially exogenous to local economic conditions. First, a structural change in China around 1990 significantly increased infrastructure investments nationwide. This change can be easily seen from figure 5, which plots the fractions of infrastructure investments within GNPs for the past two decades. Obviously, the investment ratios (both in total infrastructure and in transportation infrastructure) show a downward trend before 1990 and an upward trend after.[15] The 1994 railroad expansion in my setting could just be a

[15] Chinese national leaders changed in 1989 due to political reasons. New leaders had different preference for economy policy and this was probably the reason for the structural change.

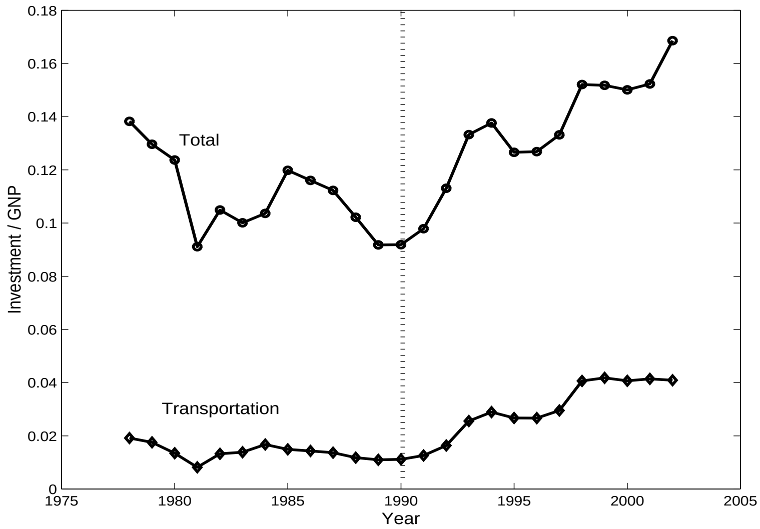

Figure 5: Chinese Infrastructure Investments as a Fraction of GNP

consequence of this structural change.

Second, the Xinjiang province, of which WU is the capital city, is separated from the rest of China by hundred of miles of desert and is bordered to a dozen central Asia countries. Therefore, the investment in the LAN-WU railroad might be used to strengthen the link between Xinjiang and the rest of China. Both reasons above suggest that the railroad-expanding project was potentially exogenous to local economic conditions.

It is important to note that even if the investment coincides with unusually high local growth rates, this would likely bias my estimates against measuring the impact of the investment on price gaps, thus making my findings stronger. To see this, note that the capacity expansion should decrease the interregional price gaps. In contrast, the fast local economic growth would likely increase demand for railroad shipping, thus driving up the price gaps and canceling out the price-gap effect of the investment.

2.4 Other Advantages of the Setting

To summarize, the empirical setting provides a prime opportunity for identifying the welfare effect of the infrastructure investment. Other important features of this setting are as follows.

First, rail-shipping is effectively the only freight-shipping method between LAN and WU. This avoids the confounding effects due to changes in other shipping modes and will also simplify my measure of the welfare gain due to the expansion (since the substitution between different shipping modes due to the rail expansion can be safely ignored). Second, the upgrading project had little effect on other railroad attributes like length or shipping-speed, saving the need to disentangle these extra factors. As the third advantage, the LAN-WU rail runs through an area where few people live. Therefore, the environmental impact of the capacity expansion, which is a main externality of transport infrastructure and is typically hard to estimate, is effectively negligible in my case.

3 Theory: Welfare Measure and Price-Gap Model

Having shown my empirical setting and how the investment in railroad may have affected interregional price gaps, in this section I formally discuss how the impact on price gaps can be estimated and how the impact may be used to infer the return to the investment.[16] A welfare measure is derived with two main assumptions: perfect competition in the goods' marketing and no effect of the investment on market demand and supply (partial equilibrium). In addition, I construct a structural model of observed price gaps. Needing no information on the shipping directions of individual goods, this model can be estimated by maximum likelihood for the separate impacts of the investment on the price gaps of goods shipped in different directions.

3.1 The Welfare Gain

I consider a theoretical setting that includes two countries (or regions), which can trade only through a single transport structure.[17] In accordance with my empirical setting, I focus on the

[16]My discussion is limited to the deadweight loss due to the distortion effects of capacity restrictions on prices and specialization. This omits other potential effects of the capacity expansion, including scale economy, markups, employment, and product variety. See Feenstra [5] for a review of how the empirical trade literature has examined these effects.

[17]This model is not limited to a two-country world. In a world with many countries, my model can still apply if these countries can be divided into two groups, with the trade between them dominated by one transport

case in which the capacity of the transport structure restricts only the trade from the home country to the foreign country. The transport capacity may be expanded and I only consider the case in which this expansion has negligible effects on the demand and supply curves of both countries. Goods in this economy are indexed by z. To begin with, I assume that the transport cost is zero.

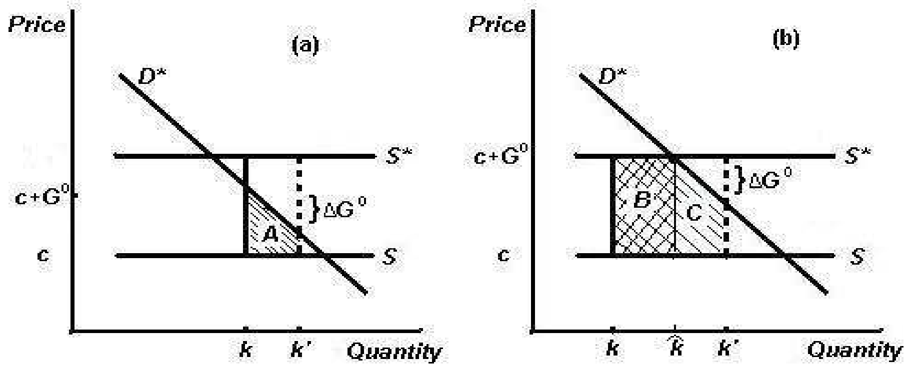

Figure 6: The Foreign Market of Good z

Figure 6 shows the foreign market for a good z, under two scenarios of capacity expansions. The foreign demand for this good is represented by D^*. Good z tends to be shipped from the home country to the foreign country because its home supply curve S (with a marginal production cost of c) is below its foreign supply curve S^*. The export of this good by the home country, however, is initially restricted by a capacity restriction k. As the total capacity expands, the capacity assigned to this good increases to k'. In scenario (a), this capacity expansion drives the foreign price of good z down from $c + G^o$ to $c + G^o - \Delta G^o$, generating a social surplus gain represented by the shaded area A. Note that, since the home price of the good is always c, the price difference of good z across the two countries is G^o before the expansion and becomes $G^o - \Delta G^o$ after the expansion. In scenario (b), the welfare gain due to an increase of capacity from k to k' can be represented by the shaded area $B + C$. In both cases, the welfare gains can be measured as follows (index z is suppressed):

structure.

$$Gain = G^o(k' - k) - \tfrac{1}{2}\Delta G^o \Delta_g k, \tag{3}$$

where $\Delta_g k$ indicates the change in home export of z due to the price-gap change ΔG^o only. In case (a), $\Delta_g k$ is the same as $k' - k$. In case (b), $\Delta_g k$ equals $k' - \hat{k}$. The areas A and C are referred to as the "price effect" of the capacity expansion; the area B, in contrast, represents the "specialization effect" of the expansion since this welfare gain results from people substituting their consumption of local product with the cheaper imported good.[18]

To compute the total social surplus gain due to the transport capacity change, we can simply integrate formula (3) over those goods that are restricted in trade by the capacity and receive extra capacity due to the expansion (assuming that the capacity change has negligible effects on the demand and supply curves). H is used to indicate the set of these goods. The formula for the total social surplus gain can be written as follows:

$$Gain = \int_H \{G^o(z)[k'(z) - k(z)] - \frac{1}{2}\Delta G^o(z)\Delta_g k(z)\}dz. \tag{4}$$

Replacing $\Delta_g k(z)$ by $k'(z) - k(z)$, formula (4) can be simplified as

$$\textit{Simplified Gain} = E_H(G^o - \tfrac{1}{2}\Delta G^o)\Delta K + COV_H(G^o - \tfrac{1}{2}\Delta G^o, \Delta k), \tag{5}$$

where ΔK indicates the total change of transport capacity, while Δk measures the change of capacity assigned to a good in the set H. $E_H(.)$ is the expectation operator, and $COV_H(.,.)$ is the covariance between two variables, all over the set H. Formulas (4) and (5) are identical if the specialization effect is negligible, such as in scenario (a) (in which $k'(z) - k(z)$ equals $\Delta_g k(z)$ by definition). If the specialization effect is present, e.g. scenario (b), the simplified formula provides a *lower bound* to the social surplus gain.

[18] Here I have implicitly assumed that the production factors for the abandoned local industry for good z can be freely reallocated. If this reallocation is not free, the specialization effect represented by B would be smaller due to the wasted resources caused by the change in specialization. Similarly, I also assume that production factors in regions outside my setting were either not affected by the investment or reallocated freely.

Supposing that a transport cost s exists and is not affected by the capacity expansion and that $COV_H(G^o - \frac{1}{2}\Delta G^o, \Delta k)$ is equal to zero, formula (5) can be augmented as[19]

$$\textit{Simplified Gain} = E_H(G^o - \tfrac{1}{2}\Delta G^o)\Delta K - s\Delta K. \tag{6}$$

This formula, which will be used in my empirical section to evaluate the social surplus gain of the capacity expansion, requires an estimate of the average price gaps of goods in set H and an estimate of the impact of the capacity expansion on these price gaps.

3.2 A Model of Price Gaps

Now that I have shown how social surplus gain is measured, I next consider the measure's necessary inputs: interregional price gaps and the impacts of a capacity expansion on them. To illustrate my empirical approach, I consider a continuum of goods indexed by real values z between 0 and 1 (the horizonal axis of figure 7). Each good z is associated with a unit production cost (which is also the good's price under competitive pricing), represented by $c(z)$ in the home country and $c^*(z)$ in the foreign country. Let the unit of price be dollar per ton. The *latent* price gap for good z is defined as follows:

$$G(z) \equiv c^*(z) - c(z). \tag{7}$$

Hence, $G(z)$ is positive if good z is cheaper in the home country, and this good tends to be exported by the home country to the foreign country. Without loss of generality, I index the goods such that function $G(z)$ decreases in z, as shown by the inverse S-shape (partly dotted) curve in figure 7. Under free trade, the home country specializes in and exports goods with indices between 0 and z_0, and imports the remaining goods, which the foreign country specializes in; moreover, the price of a good is the same in both countries under free trade, i.e. the observed price gaps are zero even though the latent price gaps are mostly not.

[19] If the transport cost changes over time, the formula would be $E(G^o - \frac{1}{2}\Delta G^o)\Delta K - s_1 K_1 + s_0 K_0$, where s_0 and s_1 are the transport costs before and after the capacity expansion, and K_0 and K_1 are the transport capacities before and after the capacity expansion.

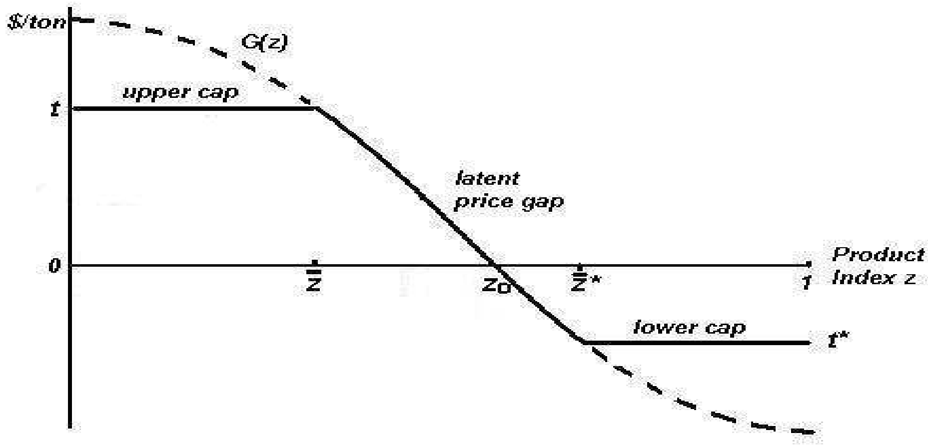

Figure 7: Price Gaps and a Capacity Expansion, over All Goods

Now suppose that trade is not free and the only trade obstacle is the capacity restriction of the transport structure between the two countries. As an illustration device, I suppose that the home country charges a fee t on each ton of any goods exported such that the transport capacity, which would be binding without the fee, exactly equals the demand for shipping. This has two immediate implications. First, only those goods with latent price gaps higher than t (goods with indices between 0 and $\bar{z}$) are specialized and exported by the home country; their observed price gaps are the same as t. Goods with indices between $\bar{z}$ and $\bar{z}_0$ are produced by both countries and not traded; their price gaps are the same as their latent price gaps. Similar reasoning applies to goods produced by the foreign country, which charges a fee t^*. The observed price gaps can thus be described by the following model:

$$G^o = \begin{cases} t & \text{if } G \geq t \\ G & \text{if } -t^* < G < t \\ -t^* & \text{if } G \leq -t^* \end{cases} \tag{8}$$

The second implication is that the price-gap cap t is a function of the transport capacity K. To see this, let $W^*(z)$ be the gross expenditure of the foreign country on importing good z; because t is chosen so that the import volume of the foreign country is the same as K, then

$$K = \int_0^{\bar{z}} \frac{W^*(z)}{t + c(z)} dz. \tag{9}$$

Rewriting this equation as $t = h(K)$ and applying the same reasoning to the foreign country, I augment the price-gap model (8) as follows:

$$G^o = \begin{cases} h(K) & \text{if } G \geq h(K) \\ G & \text{if } -h^*(K) < G < h(K) \\ -h^*(K) & \text{if } G \leq -h^*(K) \end{cases} \tag{10}$$

The uniform-user-fee scheme assumed is not crucial. The model above can be easily generalized as follows: let $t(z)$ be the user fee on good z (so it could differ across goods). In equilibrium the transport capacity, which would be binding if the fees are not levied, is equal to the demand for shipping. Under this setup, the equation (8) can be augmented by replacing t with $t(z)$, and t^* with $t^*(z)$. The principle of the equation is still the same: only goods whose latent price gaps $G(z)$ exceed their user fees will be traded, and the observed price gaps of these traded goods are the same as their corresponding user fees. Similarly, the only change needed for equation (9) is to replace t with $t(z)$. Decomposing the heterogeneous t as $\bar{t} + \epsilon$, where $\bar{t}$ is the mean of t, and t^* as $\bar{t^*} + \epsilon^*$, I can restate equations (8) and (9) as follows:

$$G^o = \begin{cases} \bar{t} + \epsilon & \text{if } G \geq \bar{t} + \epsilon \\ G & \text{if } -(\bar{t^*} + \epsilon^*) < G < \bar{t} + \epsilon \\ -(\bar{t^*} + \epsilon^*) & \text{if } G \leq -(\bar{t^*} + \epsilon^*) \end{cases} \tag{11}$$

and

$$K = \int_0^{\bar{z}} \frac{W^*(z)}{\bar{t} + \epsilon(z) + c(z)} dz. \tag{12}$$

Hence, my price-gap model (10) can be generalized as follows:

$$G^o = \begin{cases} h(K) + \epsilon & \text{if } G \geq h(K) + \epsilon \\ G & \text{if } -[h^*(K) + \epsilon^*] < G < h(K) + \epsilon \\ -[h^*(K) + \epsilon^*] & \text{if } G \leq -[h^*(K) + \epsilon^*] \end{cases} \tag{13}$$

Note 1 In the discussion above, user fees are used to ration the scarce transport capacity. This assumption is used only to facilitate my presentation, and the price-gap model allows for different forms of capacity-rationing, e.g. under-table payments to transport officials. Note that in the extreme case where the transport authority can perfectly price-discriminate the traded goods by charging fees exactly equal to the goods' latent price gaps, my three-regime price-gap model degenerates into a one-regime model: $G^o = G$.

Note 2 Transport costs should have no effects on the observed price gaps. If the transport capacity is binding, it is easy to see from equation (12) that the average observed price gap of traded goods, $\bar{t}$, is determined by capacity K but not the level of transport costs. The intuition is that: when transport cost changes, the rent due to the scarce capacity will adjust endogenously to "cancel out" the change in transport cost. If the capacity is not binding (such as the shipping from LAN to WU in my empirical setting), the transport costs still should not affect the price gaps because the two directions of shipping service are "jointly produced" (e.g., trains sent out must return to maintain service). Hence, the marginal cost of providing the shipping service in the non-capacity-restricted direction is effectively *zero* disregarding transport costs, as long as the shipping in the other direction is restricted by the capacity.

Summary I have just examined in theory how observed price gaps can be described by a regime-switching model. If the shipping directions of goods are known, observed price gaps can be divided into three regimes: goods traded from the home country to the foreign country, goods traded from the foreign country to the home country, and goods not traded. Within each regime, averages of price gaps and of the impact of the capacity expansion on price gaps can easily be calculated. The most significant benefit of the price-gap model, however, is that even if the shipping directions are unknown, it can still be estimated structurally to identify the price-gap caps and the effects of capacity expansion on them, as will be presented in the following section.

4 Empirical Estimates of the Price-Gap Effect

In the previous section I have shown that, in order to measure the welfare gain due to the capacity expansion, one needs to know the average price gaps of goods affected by the expansion as well as the change of these price gaps caused by the expansion. They can be easily estimated if the shipping directions of goods are known. The information on shipping directions, however, is not available (except for four goods). Nevertheless, the price-gap model introduced in the previous section can still be utilized to estimate the price-gap effect structurally.

4.1 Reduced-form Estimates

Before considering a full-fledged structural estimation of my price-gap model, I first estimate the price-gap effect of the expansion with a reduced-form difference-in-difference approach, which is more robust than structural estimation by relying on less stringent assumptions on the data-generating process. My treatment group includes the price gaps of gasoline, diesel, hot-rolled and cold-rolled thin steel sheets (the four products of which I can infer their shipping directions). My control groups include westbound LAN-WU price gaps and the LAN-NG price gaps. The key assumption for identifying the price-gap effect is the absence of unobserved effects that affected only the LAN-WU price gaps of the four products in the treatment group. I first consider the following regression for the treatment and control groups during 1993-1998:[20]

$$gap_{it} = \theta_i + \theta_k post_t + \epsilon_{it}, \tag{14}$$

here gap_{it} is the absolute price gap of good i at time t in unit yuan per ton. θ_i catches product-specific fixed effects. *post* refers to the post-expansion period (zero before October 1994 and one after). Therefore, θ_k is supposed to pick up the effect of the capacity expansion. ϵ_{it} is a mean zero disturbance term that is assumed to be uncorrelated with the covariates.

These reduced-form estimates (summarized in table 1) essentially quantify the graphical patterns that were shown in section two. The coefficient of the variable *post*, the capacity

[20]My price data actually span the period 1992-2001. However, the 1992 price data are not used in my regressions since, as I discuss earlier, the 1992 prices still might be under strict price regulation and may not reflect market conditions. The 1999-2001 data are not used because I want to avoid confounding effects from the increased train speed during this period. In fact, including these omitted price data does not change my findings. Specifically, with the price data during 1992-2001, I estimate that θ_k is -272.54 (60.91) for the treatment group, 23.59 (81.40) for the westbound LAN-WU price gaps of type R products, 22.28 (28.10) for the LAN-NG price gaps of type T products, and .865 (34.35) for the LAN-NG price gaps of type R products (figures in the parentheses are the standard errors).

Table 1: Reduced-form Estimates (1993-1998)

	Treatment Group	**LAN-WU (Type R)**	**LAN-NG Type T**	**LAN-NG Type R**	**Pooled D-in-D**
$Post$	-400.94^{**}	69.71	-26.07	-2.07	16.75
	(79.86)	(97.85)	(33.86)	(38.62)	(40.14)
$Treat$					-137.98
					(84.51)
$Lanwu$					256.28^{**}
					(69.87)
$Treat * post$					-49.16
					(51.87)
$Lanwu * post$					-12.67
					(76.93)
$Treat * lanwu$					377.85^{**}
					(109.28)
$Treat$					-354.93^{**}
$*lanwu * post$					(117.24)
Obs.	165	888	199	1571	3377
R^2	.48	.52	.12	.48	.44

Note: The superscript $*$ and $**$ indicate that the estimates are statistically significant at 10% and 1% levels, respectively. The same notation will be used hereafter. *post*=zero before the capacity expansion and one after. *treat*=zero for type R products and one for type T products. *lanwu*=zero for LAN-NG price gaps and one for LAN-WU price gaps. Huber-White standard errors are reported in the parentheses.

indicator, is negative and highly significant for the treatment group (i.e. the price gaps were lower after the capacity expansion). For the reference groups, the coefficients of *post* are insignificant. These estimates are consistent with my graphical findings and indicate that it is the capacity expansion that has affected the price gaps of the treatment group.

In order to obtain a statistical estimate of the *net* effect of the capacity expansion on the treatment group, I consider the following difference-in-difference type regression:

$$\begin{aligned} gap_{it} &= \theta_i + \theta_k post_t + \theta_T treat + \theta_r lanwu + \theta_{Tk} treat * post_t \\ &+ \theta_{rk} lanwu * post_t + \theta_{Tr} treat * lanwu \quad (15) \\ &+ \theta_{Trk} treat * lanwu * post_t + \epsilon_{it}, \quad (16) \end{aligned}$$

where full interaction terms of *post*, *treat*, and *lanwu* are added to regression (14). $Treat$ is a dummy variable that is zero for type R products and is one for type T products; *lanwu* is zero for LAN-NG price gaps and is one for LAN-WU price gaps. Hence, the coefficient θ_{Trk} indicates the net effect of the capacity expansion on the treatment group. The regression (15) is estimated with absolute price gaps of all goods during 1993-1998 and the estimates are reported in the last column of table 1. The net price-gap effect θ_{Trk} is estimated as -358.58 and is significant at the 1 percent level. *This means that the capacity expansion on average decreased the treatment group prices gaps by 358.58 yuan per ton (from a base of around 1000 yuan per ton) during the four years after the expansion.*

4.2 Structural Estimates

The reduced-form approach, however, is limited because it requires knowing whether the goods in question are tradable and in what directions they are traded. In the following subsection I consider a structural estimation approach, which can be applied to all goods without knowing whether they are tradable and in what directions they are traded. This approach is also able to provide estimates that have clearer economic interpretation (when estimated consistently) than the reduced-form estimates and can be readily used to test various hypotheses.

4.2.1 The Empirical Model

According to model (13), observed price gaps between LAN and WU can be modeled as follows:

$$y_{it} = \begin{cases} \underline{\lambda}_{it} & \text{if } y^*_{it} \leq \underline{\lambda}_{it} \\ y^*_{it} & \text{if } \underline{\lambda}_{it} < y^*_{it} < \bar{\lambda}_{it} \\ \bar{\lambda}_{it} & \text{if } y^*_{it} \geq \bar{\lambda}_{it} \end{cases} \tag{17}$$

here y_{it} is the observed price gap for good i at time t and y^*_{it} is the latent price gap. Price gaps of goods traded from LAN to WU (the non-capacity-restricted direction) are indicated by $\underline{\lambda}$, and price gaps of goods traded from WU to LAN (the capacity-restricted direction) are indicated by $\bar{\lambda}$. Empirically, I parameterize model (17) as follows:

$$y^*_{it} = \mathbf{x}_{it}\beta + u_{it}, \tag{18}$$

$$\underline{\lambda}_{it} = \underline{\mathbf{z}}_t\underline{\gamma} + \underline{v}_{it}, \tag{19}$$

$$\bar{\lambda}_{it} \quad = \quad \bar{\mathbf{z}}_t \bar{\gamma} + \bar{v}_{it}, \tag{20}$$

Note that $\underline{\lambda}$ and $\bar{\lambda}$ are affected by factors $\underline{\mathbf{z}}$ and $\bar{\mathbf{z}}$ that are common across contemporaneous goods traded in the same directions. Moreover, $\underline{\lambda}$ and $\bar{\lambda}$ can differ for different goods due to the idiosyncratic disturbances $\underline{v}$ and $\bar{v}$. The variable set $\mathbf{x}_{it}$, which explains the latent price gap y^*_{it}, could include the history of the dependent and independent variables.[21] Given distributional assumptions on u, $\underline{v}$, and $\bar{v}$, this non-linear model can, in principle, be estimated by maximum-likelihood. Estimate consistency can be achieved under two assumptions: conditional cross-sectional dependence and conditional serial uncorrelation.

Assumption 1: Conditional Cross-sectional *Dependence*

$$Cor(\epsilon_{it}, \epsilon_{jt} | \mathbf{x}_t, \mathbf{z}_t) \neq 0 \qquad \forall\, i \neq j \qquad where\ \epsilon \equiv [u, \underline{v}, \bar{v}] \tag{21}$$

The situation is simplified if the cross-sectional dependence is absent, but this is rarely true. Many goods are related: they may be complements or substitutes; they may have similar production inputs, such as technology, labor, capital, land, or materials. A shock to the economy may also generate cross-section correlations between the price gaps of different goods. Controlling for these factors is difficult; therefore, cross-section dependence may exist. As a result, the large-N-fixed-T asymptotics (law of large numbers holds as the number of goods goes to infinity) can not be used to establish consistency.

Assumption 2: Conditional Serial Uncorrelation

$$Cor(\epsilon_{it}, \epsilon_{is} | \mathbf{x}_i, \mathbf{z}_i) = 0 \qquad \forall\, t \neq s \qquad where\ \epsilon \equiv [u, \underline{v}, \bar{v}] \tag{22}$$

Under assumption 1, it becomes necessary to apply assumption 2 for large-T-fixed-N asymptotics (i.e., the law of large numbers holds as the number of time periods goes to infinity).

[21] In model (17) I implicitly assume that $\bar{\lambda} > \underline{\lambda}$. Note that this condition is not guaranteed by the specifications (18) through (20). This should not be of much concern empirically if $\bar{\mathbf{z}}\bar{\gamma}$ and $\underline{\mathbf{z}}\underline{\gamma}$ are far away relative to the standard deviations of the disturbance terms $\bar{v}$ and $\underline{v}$. In future studies, it would be prudent to augment the empirical model above to account for the condition $\bar{\lambda} > \underline{\lambda}$. One possible approach would be to add the constraint that $\bar{\gamma}$ is positive and $\underline{\gamma}$ is negative, as is suggested by theory. Therefore, both $\bar{\gamma}$ and $\underline{\gamma}$ can be modeled by truncated distributions. The likelihood function can then be adjusted accordingly.

Since latent price gaps are likely to be autocorrelated, assumption 2 requires the dynamics of y^* to be correctly specified.

Assumption 3: Normality and Weak Exogeneity

$$\begin{pmatrix} u_{it} \\ \underline{v}_{it} \\ \bar{v}_{it} \end{pmatrix} \mid \mathbf{x}_{it}, \mathbf{z}_{it} \sim Normal \left[\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_u^2 & 0 & 0 \\ 0 & \sigma_{\underline{v}}^2 & 0 \\ 0 & 0 & \sigma_{\bar{v}}^2 \end{pmatrix} \right] \tag{23}$$

Normality is needed to construct the likelihood function of observed price gaps. For the sake of simplicity, I also assume that u_{it}, $\underline{v}_{it}$, and $\bar{v}_{it}$ are uncorrelated (more general results are available in the appendix). Under assumption 3, the likelihood (or probability density) of y_{it} conditional on the information set $\mathbf{x}_{it}$, $\bar{\mathbf{z}}_t$, and $\underline{\mathbf{z}}_t$ can be obtained as a closed-form function (similar to those of censored regression models, e.g. Tobit).[22] Specifically, let $\phi(.)$ and $\Phi(.)$ be the p.d.f. and c.d.f. of a standard normal distribution, then the likelihood function for observed price gaps can be expressed as follows:

$$\begin{aligned} f(y_{it} \mid \mathbf{x}_{it}, \underline{\mathbf{z}}_t, \bar{\mathbf{z}}_t) &= f(\underline{\lambda}_{it} \mid \underline{\mathbf{z}}_t)\mathbf{\Phi}(\frac{u_{it}}{\sigma_u}) + f(\bar{\lambda}_{it} \mid \bar{\mathbf{z}}_t)[1 - \mathbf{\Phi}(\frac{u_{it}}{\sigma_u})] & (24) \\ &+ f(y_{it}^* \mid \mathbf{x}_{it})[1 - \mathbf{\Phi}(\frac{\bar{v}_{it}}{\sigma_{\bar{v}}})]\mathbf{\Phi}(\frac{\underline{v}_{it}}{\sigma_{\underline{v}}}) \\ &= \frac{1}{\sigma_{\underline{v}}}\phi(\frac{\underline{v}_{it}}{\sigma_{\underline{v}}})\mathbf{\Phi}(\frac{u_{it}}{\sigma_u}) + \frac{1}{\sigma_{\bar{v}}}\phi(\frac{\bar{v}_{it}}{\sigma_{\bar{v}}})[1 - \mathbf{\Phi}(\frac{u_{it}}{\sigma_u})] & (25) \\ &+ \frac{1}{\sigma_u}\phi(\frac{u_{it}}{\sigma_u})[1 - \mathbf{\Phi}(\frac{\bar{v}_{it}}{\sigma_{\bar{v}}})]\mathbf{\Phi}(\frac{\underline{v}_{it}}{\sigma_{\underline{v}}}) \end{aligned}$$

This likelihood function is a weighted sum of the density functions of y^*, $\underline{\lambda}$, and $\bar{\lambda}$. Intuitively, any observed price gap could be either the latent price gap, the lower cap, or the upper cap.

To obtain the integrated likelihood for all observations of y, information is needed about the cross-sectional dependence structure. Lacking this information, I consider below the partial likelihood method in which my likelihood to maximize is the sum of the logarithm of

[22] More closely related to my model is the disequilibrium models; see appendix for a brief discussion.

$f(y_{it} \mid \mathbf{x}_{it}, \underline{\mathbf{z}}_t, \bar{\mathbf{z}}_t)$ across products and time, i.e. $\sum_{t=1}^{T}\sum_{i=1}^{N} \ln f(y_{it} \mid \mathbf{x}_{it}, \underline{\mathbf{z}}_t, \bar{\mathbf{z}}_t)$. Large-$T$-fixed-$N$ asymptotics can then be applied to show that the MLE estimates are consistent under the assumptions.

4.2.2 Empirical Specification and Testable Hypotheses

In my empirical exercise, I specify $\underline{\lambda}_{it}$, $\bar{\lambda}_{it}$, and y^*_{it} as follows:

$$y^*_{it} = \beta_i + \beta_t t + \beta_l y_{i,t-1} + u_{it}, \tag{26}$$

$$\underline{\lambda}_{it} = \underline{\gamma}_0 + \underline{\gamma}_t t + \underline{\gamma}_k K_t + \underline{\gamma}_s s_t + \underline{\gamma}_p p^*_{it} + \underline{v}_{it}, \tag{27}$$

$$\bar{\lambda}_{it} = \bar{\gamma}_0 + \bar{\gamma}_t t + \bar{\gamma}_k K_t + \bar{\gamma}_p p_{it} + \bar{v}_{it}, \tag{28}$$

where t indicates time. The fixed effect specific to product i is picked up by β_i. This fixed effect has an important economic interpretation: the comparative advantage of two regions represented by LAN and WU in producing good i. The capacity expansion indicator, K_t, is zero before October 1994 and one after that date. The variable s_t represents the official shipping rate at time t. Furthermore, p_{it} is the price of good i at WU at time t, and p^*_{it} is the price of good i at LAN at time t. In the latent price gap equation (26) I include a one-period lagged variable of the *observed* price gap to account for the dynamics of latent price gaps. The variables t, s, p, and p^* are all de-meaned such that their sample averages are all zero. Hence, $\underline{\gamma}_0$ and $\bar{\gamma}_0$ indicate the average price gaps of goods traded westbound and eastbound. The hypotheses to be tested are summarized as follows.

Hypothesis 1: $\bar{\gamma}_0 > 0$ Goods traded in the capacity-restricted direction should have positive price gaps. This hypothesis also suggests that goods traded are not perfectly price-discriminated.[23]

Hypothesis 2: $\bar{\gamma}_k < 0$**,** $\underline{\gamma}_k = 0$ If the capacity expansion did have an effect, the observed price gaps for goods shipped eastbound (from WU to LAN) should have decreased. In

[23] As discussed in my theory section, if the goods are perfectly price-discriminated, the three-regime price-gap model degenerates into a single-regime model so that the price gaps of different trading directions can not be identified.

contrast, the westbound shipment through the LAN-WU rail was not subject to the capacity restriction, so the westbound price gaps should not have been affected by the capacity change.

Hypothesis 3: $\underline{\gamma}_s = 0$ As predicted by the "joint-product" theory, transport costs have no effect on price gaps of goods whose shipment is not restricted by the transport capacity.

4.2.3 Empirical Findings

In order to measure the impact of the capacity expansion on price gaps, I estimate the price-gap model with the price data during 1992-1998 for the twelve industrial products. I also obtain information on official shipping rates (table 2) and use them to approximate the transport cost, which is needed to test the "joint-product" hypothesis. Table 3 summarizes my estimation results.[24] In the first column, I report estimates when the lagged variable $y_{i,t-1}$ is not included, and in the second column I report estimates with $y_{i,t-1}$ included.

Table 2: Average Official Shipping Rates
Unit: yuan/(ton*kilometer)

Time	LAN-WU	LAN-NG
Before 3/1/91	.0265	.0265
3/1/91 - 6/30/92	.029	.029
7/1/92 - 9/30/92	.0385	.0385
10/1/92 - 6/30/93	.043	.0385
7/1/93 - 12/25/95	.058	.0535
12/26/95 - 1/31/96	.083	.0785
2/1/96 - 3/31/96	.0802	.0785
4/1/96 - 6/1/97	.0872	.0855

Source: *Chinese Price Yearbook*.

[24] I use the maximization procedure "maxlik.m" as is available in the "Econometrics Toolbox" (for Matlab) that can be downloaded online. For the Hessian method I choose BFGS (Broyden, Fletcher, Goldfarb, and Shanno 1970). I try different starting values for the variances of the disturbance terms and report those resulting in the largest likelihood.

Table 3: Price-Gap Model Estimates

	Estimates with Static y^*	Estimates with AR(1) y^*
$\beta_{cold-sheet}$	774.30** (45.27)	292.56** (73.07)
$\beta_{hot-sheet}$	401.38** (64.57)	124.32 (93.06)
$\beta_{gasoline}$	413.57** (41.26)	160.89* (53.18)
β_{diesel}	398.46** (41.32)	151.91* (52.37)
β_{steel3}	29.56 (52.88)	-52.55 (66.95)
β_{steel4}	137.76* (45.62)	1.79 (53.25)
β_{steel5}	36.94 (44.40)	34.49 (57.06)
β_{steel6}	−90.50* (41.97)	-66.17 (50.90)
β_{steel7}	-77.40 (46.52)	8.33 (57.21)
$\beta_{sodium1}$	20.08 (48.15)	20.13 (55.52)
$\beta_{sodium2}$	-30.04 (44.31)	8.75 (52.27)
β_{cement}	-31.89 (41.25)	6.70 (48.79)
β_t	-25.84 (68.92)	-11.48 (94.24)
β_l		.66** (.059)
$\bar{\gamma}_0$	1000.3** (87.19)	1000.6** (120.76)
$\bar{\gamma}_t$	7.89 (28.89)	26.15(37.69)
$\bar{\gamma}_k$	−299.78* (118.69)	−299.58* (160.22)
$\bar{\gamma}_p$	.13** (.033)	.11* (.043)
$\underline{\gamma}_0$	-757.78 (1851)	-797.75 (3306)
$\underline{\gamma}_t$	.67 (303.4)	1.01 (470.1)
$\underline{\gamma}_k$	-.001 (13.14)	-.001 (26.32)
$\underline{\gamma}_s$	-1.002 (15.79)	-1.003 (28.25)
$\underline{\gamma}_p$	−.18* (.07)	-.19 (.13)
Number of Observations	600	432
Likelihood	-4226.3	-2918.7

Note 1: All price data during 1992-1998 for the twelve industrial products are used in this estimation.
Note 2: The starting values for the variances of u, $\underline{v}$, and $\bar{v}$ are 100000, 100000, and 10000, respectively. They change little after the maximization process. Standard errors are noted in the parentheses.

In the above table, the coefficient β_l for $y_{i,t-1}$ is estimated as .66 and is highly statistically significant. Nevertheless, controlling for the autocorrelation of price gaps has little effect on the estimates for the price gap cap parameters. This finding reduces concern that potential misspecification of the dynamic structure would significantly bias my estimates. Other main findings are summarized below.

Price-Gap Caps: The price gaps of goods shipped eastbound is significant and estimated precisely as 1000 yuan per ton (before the capacity expansion), suggesting that these goods are not perfectly price-discriminated in using the capacity (hypothesis 1). In contrast, the estimate for the westbound price gaps is insignificantly different from zero.

Capacity Effect: The effect of the capacity expansion on the eastbound price gaps, as measured by $\bar{\gamma}_k$, is -300 yuan per ton and is significant at 10 percent level (hypothesis 2). Note that this estimate is similar to that from the reduced-form regression. In contrast, the capacity expansion had negligible effects on the westbound price gaps; $\underline{\gamma}_k$ is estimated as -.001 yuan per ton and, is insignificant.

Transport Cost: The coefficient for the shipping cost is highly insignificant, as is consistent with the prediction of the joint-product theory (hypothesis 3).

Price Effects: The relationship between price levels and price gaps,$\bar{\gamma}_p$ and $\underline{\gamma}_p$, is significantly estimated. In particular, as the price of goods shipped eastbound lowered by 1000 yuan per ton, the price gaps of the goods would lower by over 100 yuan per ton. A similar positive relationship is found for goods shipped westbound. This finding suggests that, besides transport costs, there are other trade impediments that are associated with product values. For example, user fees may be charged per dollar of goods shipped (i.e. price-discrimination). Labor and capital costs for handling interregional trade may also be correlated with the value of goods traded.

Product Fixed Effects: The fixed effects for gasoline, diesel, and thin steel sheets are positive and significant. The fixed effects for other products are not significant when $y_{i,t-1}$, the one-period lagged variable of observed price gaps, is included in the model.

Time Trends: The latent price gaps, the upper caps, and the lower caps all show some time trends, but none at a significant level.

5 The Welfare Effect

Now that I have estimated the price-gap model, I am ready to apply formula (6) to measure the social surplus gain due to the railroad expansion. Recall that this measure only provides a lower bound to the true gain if there is a specialization effect due to the capacity expansion. Moreover, my estimates rely on a couple of assumptions as mentioned earlier, e.g. perfect competition and partial equilibrium.

In order to compute formula (6), I input the change of transport capacity, the average price gap of goods shipped from WU to LAN, the average impact on these price gaps of the capacity expansion, and the shipping costs between WU and LAN. The LAN-WU rail capacity increased from about 12 million tons per year during 1990-1994 to 17 million tons per year during 1995-1998 (see figure 2). This capacity change is estimated to decrease the eastbound price gaps from 1,000.6 to 701.0 yuan per ton (see table 3). During my sample period, official shipping rates increased from 47.7 to 156.96 yuan per ton (calculated by the rates in table 2 and the length of LAN-WU rail, 1,800 kilometers). To account for unobserved shipping charges, e.g. uploading and unloading fees, I consider four scenarios of the total transport cost (100, 200, 300, and 400 yuan per ton). Note that, under each scenario, the transport cost is kept constant during my sample period. This is reasonable considering the expansion did not affect the speed and length of LAN-WU rail-shipping, thus having little effect on the real transport cost.

Table 4: Social Surplus Gains

	Case 1	**Case 2**	**Case 3**	**Case 4**
Eastbound Price Gaps (yuan/ton)	1000.6 (120.76)			
Decrease of Eastbound Price Gaps(yuan/ton)	299.58 (160.22)			
Increase of Capacity (million tons/year) (1995-1998)	5			
Total Transport Cost (yuan/ton)	100	200	300	400
Social Surplus Gain (billion yuan/year) (1995-1998)	3.75 (.28)	3.25 (.28)	2.75 (.28)	2.25 (.28)

Note: Standard errors are noted in the parentheses. The standard error for the social surplus gain is calculated with $Var(G^o) = 14,582$ $(yuan/ton)^2$, $Var(\Delta G^o) = 25,669$ $(yuan/ton)^2$, and $COV(G^o, \Delta G^o) = -17,886$ $(yuan/ton)^2$, as are estimated from my structural price-gap model.

Table 4 shows that the estimated social surplus gains are substantial. In the most conservative case considered (the transport cost is 400 yuan, or 50 dollars, per ton), the gain would be around 2.25 billion yuan, or 280 million dollars, per year. To better understand how large these gains are, below I provide an estimate of the project's internal rate of return i, which is defined as the discount rate that would make the present value of the project's net benefits exactly zero (see Gramlich [9] Chapter 6 for a detailed discussion). Mathematically, it can be represented as

$$0 = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+i)^t}, \tag{29}$$

where B_t and C_t are the benefits and costs of the project at time t. Since I have estimated the benefits only for the period 1995-1998 due to data restrictions, below I confine my measures of the internal rate of return to two special cases, which are highly simplified but can provide a bound on the actual return. In the first case I suppose that the new capacity was effective only for the period 1995-1998. This obviously underestimates the gross benefit, so the calculated internal rate of return can be seen as a lower bound. Alternatively, I suppose that the new capacity is effective for *all* years after it was added; this may thus provide an upper bound to the actual internal rate of return.

The cost of the capacity expansion project is not directly known but may be inferred as below. According to the *Chinese Transportation Yearbook* (1994, pp.61, pp. 420, and pp. 423), by the end of 1993, half of the upgrading project was completed and about 2.37 billion yuan had been spent. From this I infer that the second half of the project, which was completed in 1994, also cost the same amount of money.[25] Therefore, the internal rates of return for the two hypothetical cases can be obtained from the following two equations:

Case 1: $0 = \frac{-2.37}{(1+i_1)^0} + \frac{-2.37}{(1+i_1)^1} + \sum_{t=2}^{5} \frac{B_t}{(1+i_1)^t} \quad \Rightarrow \quad \frac{1-\frac{1}{(1-i_1^5)}}{1-\frac{1}{(1-i_1^2)}} = \sqrt{\frac{2.37}{B}+1} \quad \text{if } B_t = B$

Case 2: $0 = \frac{-2.37}{(1+i_2)^0} + \frac{-2.37}{(1+i_2)^1} + \sum_{t=2}^{\infty} \frac{B_t}{(1+i_2)^t} \quad \Rightarrow \quad i_2 = \sqrt{\frac{B}{2.37}+1} - 1 \quad \text{if } B_t = B$

here t is the number of years after the project was started, e.g. $t = 2$ for year 1995.

[25] According to another source, a report by Xinhua News Agency on July 1, 1995, the total project cost was about four billion yuan (470.5 million us dollars).

Table 5: Internal Rates of Return

	$Cost = 100$	$Cost = 200$	$Cost = 300$	$Cost = 400$
B (billion yuan/year)	3.75 (.28)	3.25 (.28)	2.75 (.28)	2.25 (.28)
i_1 (%)	42.78 (4.64)	34.41 (8.26)	25.35 (18.63)	15.39 (67.00)
i_2 (%)	60.69 (3.68)	53.99 (3.84)	46.98 (4.02)	39.62 (4.23)

Note: Standard errors, reported in the parentheses, are approximated by the Delta Method.

Table 5 summarizes the internal rates of return calculated for different scenarios. In the most conservative case considered (listed in row 1 column 4), the internal rate of return is still high at 15.4% (the capacity was effective for only four years and the total transport cost was 400 yuan per ton). If the project's life extends to infinity, the return would increase to around 40% (row 1 column 1). The highest rate of return, 60.69%, is obtained when the added capacity lasts infinitely and the total transport cost is only 100 yuan per ton.

In order to judge whether the investment is economically sensible, the internal rates of return can be compared with the opportunity cost of capital. I obtain the long-term (over five years) nominal loan rates in China during my sample period (see table 6). I then determine the real interest rate by controlling for inflation (by general retail price index) during the same period in China. From 1990 to 1999, real rates fluctuated and were as high as 10 percent. The project thus seems to be a wise one since all my estimates for the internal rates of return are above the highest real interest rates, 10.2 percent (all estimates, except for the most conservative case, are one standard deviation above 10.2 percent).

Table 6: Long-term Loan Rates in China

	90	91	92	93	94	95	96	97	98	99
Nominal Annual Rate (%)	12.0	11.2	9.7	14.0	14.0	15.3	15.3	10.4	7.6	6.2
Real Annual Rate (%)	9.9	8.3	4.3	.8	-6.3	.5	9.2	9.6	10.2	9.2

Source: *Chinese Financial Yearbook* and *Chinese Statistical Yearbook*

Notes The wide range of my estimated social surplus gain is mainly due to the empirical limitation of data. Policy makers can use the approach in this study to obtain a much more precise estimate of the welfare gain with better information on the transport costs, the project cost, and how it is financed. Moreover, in the exercise above I have utilized the price gaps of only twelve products that could be traded between LAN and WU. An assumption implicit in my estimation is that the price gaps of these products are representative of the price gaps of all goods traded from WU to LAN and affected by the capacity expansion. Therefore, larger and more representative price data set will help improve my estimates. Last but not least, my estimates may also be further refined by evaluating the benefit for *each* year when the capacity is effective. For the sake of simplicity, I have assumed that the capacity and price gaps are the same for every year after the capacity expansion. This is obviously not true since the actual capacity increased gradually after the expansion and did not reach the new theoretical capacity until around 2000. Over time, effective capacity could also deteriorate.

6 Concluding Remarks

Applying a new empirical approach to a favorable empirical setting, this study provides new econometric evidence on the welfare gain of infrastructure investment. Specifically, I consider a project that expanded the capacity of a railroad in China. Utilizing price differences across cities and the impact on them of the investment, I find that the capacity expansion generated substantial social surplus gains (over 280 million dollars). These gains correspond to significant internal rates of return, which are higher than the return to private investments even in my most conservative scenario.

One obvious future research topic would be to employ my favorable empirical setting to explore economic effects of the expansion other than the price-gap effect considered in this study. These other effects could include deepening in specialization, changes in productivity (e.g. due to market integration or technology spillover), changes in producer markups, effects on employment, and changes in product variety (see Feenstra [5] for related discussion in the trade literature).

It should also prove fruitful to apply my methodology to investments in congested highways. Highways are typically more important than railroads in modern economies and have received much attention from researchers. This literature, however, has paid little attention to the effect of highway congestion on interregional trade and to its related welfare consequence. This trade effect is potentially important; a survey (Golob and Regan [8]) of 1200 managers of all types of trucking companies operating in California found that more than 80% considered traffic congestion on freeways and surface streets to be either a somewhat serious or critically serious problem.

APPENDIX

Trade between Xinjiang and Neighbor Countries

The Xinjiang province borders eight countries — Mongolia, Russia, Kazakhstan, Kyrgyzstan, Tajikistan, Afghanistan, Pakistan, and India. These countries are all located over 500 miles away from WU (the capital of Xinjiang). Shipping between Xinjiang and these countries relied *only* on highways until October 11, 1992, when a railroad between WU and Kazakhstan (460 miles) was completed.

Detailed information is not available on the trade volumes between Xinjiang and the eight countries. Nevertheless, available evidence suggests that the trade volumes were negligible before 1992 due to poor transportation conditions. Since 1992, trade between WU and Kazakhstan has dramatically increased and dominated the foreign trade of Xinjiang (see table 7). The first row shows Xinjiang's import values during 1990-1996. The imports tripled in 1992 and grew rapidly afterwards. This change is consistent with the completion of the WU-Kazakhstan railroad. In rows two through five, import volumes for steel, chemical fertilizer, industrial chemicals, and paper are reported. Among them, steel imports have increased the most. In 1992, steel imports doubled; in 1993, steel imports increased by ten-fold. After 1993, steel imports shrank but remained much larger than before 1992. This suggests that steel imports from Kazakhstan constituted a major portion of total imports, especially of steel, to Xinjiang. In the last row I also show the export values of Xinjiang, and similar increasing trade patterns are found.

Table 7: Foreign Imports and Exports of Xinjiang

	90	**91**	**92**	**93**	**94**	**95**	**96**
Imports of Xinjiang							
Total Value ($10^6 US\$$)	75.0	96.2	296.5	427.0	464.4	659.2	853.9
Steel (ton)	48,019	30,954	65,476	711,759	335,434	356,869	581,945
Chemical Fertilizer (ton)	209,967	298,184	700,187	275,759	191,045	398,680	787,300
Industrial Chemicals (ton)	701	4,262	18,268	3,529	9,951	35,668	17,176
Paper (ton)	4	0	2,649	9,985	4,884	79	52,146
Exports of Xinjiang							
Total Value ($10^6 US\$$)	335.3	363.2	453.9	495.1	576.1	768.8	549.8

Source: *Xinjiang Statistical Yearbook.*

Trade Directions

I propose two alternative ways to identify the shipping direction of a good. Firstly, I can examine the commodity's *net flow* as calculated below[26]:

$$Net\ Flow\ from\ Xinjiang\ to\ Other\ Provinces = Xinjiang's\ Local\ Production$$

$$-Xinjiang's\ Local\ Consumption\ - Xinjiang's\ Exports\ to\ Foreign\ Countries.$$

If this net flow was positive for a product, then some amount of it must have been shipped eastbound through the LAN-WU rail. Therefore, this product's price gaps should be affected by the capacity change. Following this observation, one may be tempted to infer that a product with a negative net flow is shipped westbound so that its price gaps are not affected by the capacity-change. This is not true: note that even if a product's *net* flow was negative, it is still possible that some amount of this good was shipped eastbound. If this happened, the product's price gaps would be affected by the capacity change.

[26]Implicitly I am assuming that the inventory of the product either is small or does not change much over time, so that the inventory can be omitted from the analysis.

As an alternative approach, I can examine the *signs* of observed price gaps. Intuitively, a commodity tends to flow from a low-price city to a high-price city.[27] Even if price gaps exist, trade may not occur due to trade impediments. Therefore, if a good was found to be cheaper in LAN (eastern) than in WU (western), then it was either not shipped or shipped westbound; in either case, the good's price gaps should *not* be affected by the rail-capacity change. However, if the good was more expensive in LAN than in WU, it is hard to say whether its price gaps should or should not be affected by the capacity expansion; it depends on whether the good was actually traded, which is unknown.

Table 8: Xinjiang's Production, Consumption, and Trade of Gasoline, Diesel, and Thin sheet steel

Unit: ton

Year	**Product**	**Loc Prod.**	**Loc Cons.**	**Exports**	**Imports**
	Gasoline	1,410,000	785,500	-	-
91	Diesel	1,560,000	956,400	-	-
	Thin Sheet	0	98,941	-	-
	Gasoline	1,590,000	954,600	0	0
92	Diesel	1,810,800	1,032,000	0	0
	Thin Sheet	0	100,152	0	1,941
	Gasoline	1,866,300	1,144,300	0	0
93	Diesel	2,005,100	1,056,000	0	3,312
	Thin Sheet	0	97,316	0	135,945
	Gasoline	1,745,900	1,052,200	-	-
94	Diesel	2,140,700	1,162,800	-	-
	Thin Sheet	0	97,316	0	135,945
	Gasoline	1,790,000	1,019,600	308	0
95	Diesel	2,318,800	1,212,000	490	0
	Thin Sheet	0	93,727	0	213,124
	Gasoline	1,983,200	1,043,000	592	0
96	Diesel	2,643,400	1,271,700	0	0
	Thin Sheet	0	77,373	0	626,474
	Gasoline	2,084,300	973,700	0	0
97	Diesel	3,044,200	1,250,600	0	0
	Thin Sheet	0	86,999	0	700,155

Source: *Chinese Steel Statistical Yearbook* and *Xinjiang Statistical Yearbook*.

Based on the two methods above, I find strong evidence for the shipping directions of

[27] A sufficient condition for this is competitive pricing. In this study, competitive pricing is not an unreasonable assumption for most of the products — especially agricultural products, so the signs of the price gaps can be used as an indicator.

three commodities — gasoline, diesel, and thin sheet steel. As shown in table 8, local production of gasoline and diesel in the Xinjiang province significantly exceeded local consumption; moreover, their China-Kazakhstan trade volumes were negligible during my sample period.[28] Therefore, the net flows of gasoline and diesel from Xinjiang to other provinces are significantly positive. The local output level of thin sheet steel in Xinjiang was zero throughout my sample period; in contrast, its local consumption in Xinjiang was substantial. Therefore, before 1993, its net flow was negative. After 1993, however, the net flow became positive since the imports of thin sheet steel increased dramatically due to the completion of the WU-Kazakhstan railroad.

As a further check, I also consider the signs of these products' price gaps, e.g. their prices in LAN minus their prices in WU. In the top-left panel of figure 4 I plot the three products' average LAN-WU price gaps. The price gaps were all positive during 1992-1997, as is generally consistent with the flow directions I inferred above. To summarize, gasoline, diesel, and thin sheet steel should be shipped eastbound after 1992.

For other products, the net-flow approach is much less effective either because high-quality data are not available or because the implied net flows are too small to be robust to measurement errors. Nevertheless, the sign-of-price-gap approach can still be used to find goods that were cheaper in LAN than in WU (the goods whose price gaps should not be affected by the capacity expansion).

The Price-Gap Model

The price-gap model is closely related to the classical disequilibrium model, as discussed in Maddala [13]:

$$y^* = \mathbf{x}\beta + u, \tag{30}$$

[28]Ideally, I need information on Xinjiang's foreign trade volumes. However, this information is unavailable. Nevertheless, since Kazakhstan borders upon no Chinese provinces other than Xinjiang and since Kazakhstan is the only foreign country to which Xinjiang is connected to by a railroad, the China-Kazakhstan trade volume can be used to approximate that between Xinjiang and foreign countries.

$$\lambda = \mathbf{z}\gamma + v, \tag{31}$$

$$y = y^* \quad if\ y^* < \lambda, \tag{32}$$

$$= \lambda \quad if\ y^* \geq \lambda, \tag{33}$$

where

$$\begin{pmatrix} u \\ v \end{pmatrix} \mid \mathbf{x}, \mathbf{z} \sim Normal \begin{pmatrix} \sigma_u^2 & \sigma_{uv} \\ \sigma_{vu} & \sigma_v^2 \end{pmatrix}. \tag{34}$$

Below is the price-gap model in this study:

$$\begin{aligned} y_{it} &= \underline{\lambda}_{it} \quad if\ y_{it}^* \leq \underline{\lambda}_{it}, \\ &= y_{it}^* \quad if\ \underline{\lambda}_{it} < y_{it}^* < \bar{\lambda}_{it}, \\ &= \bar{\lambda}_{it} \quad if\ y_{it}^* \geq \bar{\lambda}_{it}, \end{aligned} \tag{35}$$

where

$$\begin{aligned} y_{it}^* &= h(\mathbf{x}_{it}, \beta) + u_{it}, \\ \underline{\lambda}_{it} &= \underline{h}(\underline{\mathbf{z}}_t, \underline{\gamma}) + \underline{v}_{it}, \\ \bar{\lambda}_{it} &= \bar{h}(\bar{\mathbf{z}}_t, \bar{\gamma}) + \bar{v}_{it}, \end{aligned}$$

and

$$\begin{pmatrix} u \\ \underline{v} \\ \bar{v} \end{pmatrix} \mid \mathbf{x}, \mathbf{z} \sim Normal \begin{pmatrix} \sigma_u^2 & \sigma_{u\underline{v}} & \sigma_{u\bar{v}} \\ \sigma_{\underline{v}u} & \sigma_{\underline{v}}^2 & 0 \\ \sigma_{\bar{v}u} & 0 & \sigma_{\bar{v}}^2 \end{pmatrix}. \tag{36}$$

Its likelihood function is as follows:

$$\begin{aligned} f(y_{it} \mid \mathbf{x}_{it}, \underline{z}_{it}, \bar{z}_{it}) &= f(\underline{\lambda}_{it} \mid y_{it}^* < \underline{\lambda}_{it}) p(y_{it}^* < \underline{\lambda}_{it}) + f(\bar{\lambda}_{it} \mid y_{it}^* > \bar{\lambda}_{it}) p(y_{it}^* > \bar{\lambda}_{it}) \\ &\quad + f(y_{it}^* \mid \underline{\lambda}_{iy} \leq y_{it}^* \leq \bar{\lambda}_{it}) p(\underline{\lambda}_{it} \leq y_{it}^* \leq \bar{\lambda}_{it}) \end{aligned} \tag{37}$$

$$
\begin{aligned}
&= \frac{1}{\sigma_{\underline{v}}}\phi(\frac{\underline{v}_{it}}{\sigma_{\underline{v}}})[1-\boldsymbol{\Phi}(\frac{h(\mathbf{x}_{it},\beta)-\underline{h}(\underline{\mathbf{z}}_{it},\underline{\gamma})-\frac{\sigma_{\underline{v}}^2-\sigma_{u\underline{v}}}{\sigma_{\underline{v}}^2}\underline{v}_{it}}{\sigma_{\underline{\eta}}})] \qquad (38)\\
&+ \frac{1}{\sigma_{\bar{v}}}\phi(\frac{\bar{v}_{it}}{\sigma_{\bar{v}}})\boldsymbol{\Phi}(\frac{h(\mathbf{x}_{it},\beta)-\bar{h}(\bar{\mathbf{z}}_{it},\bar{\gamma})-\frac{\sigma_{\bar{v}}^2-\sigma_{u\bar{v}}}{\sigma_{\bar{v}}^2}\bar{v}_{it}}{\sigma_{\bar{\eta}}})\\
&+ \frac{1}{\sigma_u}\phi(\frac{u_{it}}{\sigma_u})[1-\boldsymbol{\Phi}(\frac{h(\mathbf{x}_{it},\beta)-\bar{h}(\bar{\mathbf{z}}_{it},\bar{\gamma})-\frac{\sigma_{u\bar{v}}-\sigma_u^2}{\sigma_u^2}u_{it}}{\sigma_{\bar{\xi}}})]\\
&\times \boldsymbol{\Phi}(\frac{h(\mathbf{x}_{it},\beta)-\underline{h}(\underline{\mathbf{z}}_{it},\underline{\gamma})-\frac{\sigma_{u\underline{v}}-\sigma_u^2}{\sigma_u^2}u_{it}}{\sigma_{\underline{\xi}}})
\end{aligned}
$$

where

$$
\begin{aligned}
\sigma_{\underline{\xi}} &= \sqrt{\sigma_u^2+\sigma_{\underline{v}}^2-2\sigma_{u\underline{v}}-(\frac{\sigma_{u\underline{v}}-\sigma_u^2}{\sigma_u^2})^2\sigma_u^2}\\
\sigma_{\bar{\xi}} &= \sqrt{\sigma_u^2+\sigma_{\bar{v}}^2-2\sigma_{u\bar{v}}-(\frac{\sigma_{u\bar{v}}-\sigma_u^2}{\sigma_u^2})^2\sigma_u^2}\\
\sigma_{\underline{\eta}} &= \sqrt{\sigma_u^2+\sigma_{\underline{v}}^2-2\sigma_{u\underline{v}}-(\frac{\sigma_{u\underline{v}}-\sigma_{\underline{v}}^2}{\sigma_{\underline{v}}^2})^2\sigma_{\underline{v}}^2}\\
\sigma_{\bar{\eta}} &= \sqrt{\sigma_u^2+\sigma_{\bar{v}}^2-2\sigma_{u\bar{v}}-(\frac{\sigma_{u\bar{v}}-\sigma_{\bar{v}}^2}{\sigma_{\bar{v}}^2})^2\sigma_{\bar{v}}^2}
\end{aligned}
$$

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